CLEAR VISION ON TURBID WATER: THE NAIVASHA LAKE

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Outlines

- Study Area
- The problem
- Objectives
- Field data
- Hydro optical models
  - Empirical: CDOM, Chl-a and KD
  - Cal/Val of the empirical models
  - Semi analytical including NAP
  - Errors
- Depth profile of Kd: a new method
- Preliminary conclusions
Study area
Study area

- Home for over 400 bird species
- Wild animals
- Tourist area
- Horticulture
- Fishing
- Fresh water!

1mil$ a day!!
Problem

“The Naivasha Lake is becoming an over-enriched muddy pool, which will shortly become unusable.”

“ It is only a matter of time before the lake becomes toxic”

(Harper, 2004)
Problem as experienced!

On march, 2010 after a heavy rains
Objectives

The main objectives here are:

- Accounting for the NAP and phycocyanin absorptions and derive the spectral slopes;
- Investigate semi empirical models for CDOM, Chl-a and Kd;
- Investigate the errors of IOP and their sources;

**Suggest new forward model to get Kd on different depths;**
Field data

Optical and biophysical measurements

<table>
<thead>
<tr>
<th>IOPs</th>
<th>Max</th>
<th>Min</th>
<th>Average</th>
<th>Stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_{\text{Chl}_a}$ (m$^{-1}$)</td>
<td>3.28</td>
<td>1.14</td>
<td>2.38</td>
<td>0.43</td>
</tr>
<tr>
<td>$a_{\text{CDOM}}$ (m$^{-1}$)</td>
<td>3.45</td>
<td>0.92</td>
<td>2.47</td>
<td>0.61</td>
</tr>
<tr>
<td>$a_t$ (m$^{-1}$)</td>
<td>19.23</td>
<td>3.69</td>
<td>10.21</td>
<td>3.06</td>
</tr>
<tr>
<td>$a_{\text{NAP}}$ (m$^{-1}$)</td>
<td>14.95</td>
<td>0.00</td>
<td>5.55</td>
<td>2.94</td>
</tr>
<tr>
<td>SPM(mg/l)</td>
<td>58.33</td>
<td>1.00</td>
<td>29.92</td>
<td>12.27</td>
</tr>
<tr>
<td>$S_{\text{CDOM}}$(sr$^{-1}$)</td>
<td>0.026</td>
<td>0.01</td>
<td>0.0135</td>
<td>0.003</td>
</tr>
<tr>
<td>$S_{\text{NAP}}$(sr$^{-1}$)</td>
<td>0.007</td>
<td>0.001</td>
<td>0.004</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Results of field data

Chart of absorptions of water constituents in lake Naivasha
Results of field data

- lake Naivasha
- hippo pool
- flower industry
- Crater lake
- gilgil inlet
- lake center

$y = 619.37e^{-0.012x}$

$R^2 = 0.9976 \text{ (N = 93)}$
Hydro optical models

- Empirical algorithms
  - Use statistical relationships to link observed radiometric quantities to measured IOP’s.

- Semi analytical algorithms
  - Use approximations of radiative transfer and empirical relationships to provide invertible linkages between the AOPs and the IOPs
    - Capability to retrieve several parameters simultaneously because they model the optical properties *(maybe!)*
Comparison between retrieved and in situ measured $a_{CDOM}/a_t$ at 412 nm

The model of Belanger et al. (2008)
Results of the empirical model: Chl-a

3B Algorithm by (Gitelson et. al 2008)
SCI Algorithm by (Shen et al 2010) &
FLH Algorithm(Gower1994,1995)

<table>
<thead>
<tr>
<th>Model</th>
<th>n</th>
<th>r²</th>
<th>RMSE</th>
<th></th>
<th>Model</th>
<th>n</th>
<th>r²</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3B</td>
<td>48</td>
<td>0.75</td>
<td>0.04</td>
<td></td>
<td>3B</td>
<td>42</td>
<td>0.8</td>
<td>0.058</td>
</tr>
<tr>
<td>SCI</td>
<td>48</td>
<td>0.21</td>
<td>0.11</td>
<td></td>
<td>SCI</td>
<td>19</td>
<td>0.49</td>
<td>0.139</td>
</tr>
<tr>
<td>FLH</td>
<td>48</td>
<td>0.18</td>
<td>0.15</td>
<td></td>
<td>FLH</td>
<td>19</td>
<td>0.21</td>
<td>0.151</td>
</tr>
</tbody>
</table>
Results of the empirical model: Kd

Austin and Petzold (1981)

\[ K_d(\lambda) = \alpha \left[ \frac{R_{rs}(555)}{R_{rs}(\lambda)} \right]^\beta + \gamma \]
Cal/Val

GeoCalVal is a novel model that provides the:
1- optimal subdivision of matchup data set into Cal and Val sets;
2- accuracy of calibration coefficients
3- probability distribution of the validation errors.

Derived probability distributions (PDs) of calibration coefficients (d, e) and validation errors (f) for Chla absorption per unit concentration.

Determination coefficient, $R^2$, between measured and observed values of Chla absorption coefficient from many Cal/Val setups. Light-grey coloured points represent the optimal Cal/Val pairs.

Salama et al., 2012, Biogeosciences, 9, 2195–2201
Hydro optical models

- One of the most used semi analytical model is the GSM model which was developed by Gordon et al., (1988), improved by Garber-Siegl and Maritorena abbreviated as GSM and recently modified by Salama, et al (2009).

\[ R_{rs}(\lambda) = \frac{t}{n_w^2} \sum_{i=1}^{2} g_i \left( \frac{b_b(\lambda)}{b_b(\lambda) + a(\lambda)} \right)^i \]

\[ a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{adg}(\lambda) \]

Limitations

- Could not separate CDOM and NAP absorption
- Is it good for Kd at different depths?
Including NAP and PC

Salama et al. in preparation

Doxaran et al., (2009)

NAP

phycocyanin

620 nm

10 nm

Doxaran et al., (2009)

$b_{\text{pna}}$ extrapolated from the near-IR (715 - 870 nm) using a power-law function

$\Delta b_p$

Measured $b_p$

Measured $\alpha_p$

$W$
Results

Field spectra are inverted to IOP and compared to the measured ones.
Results

Matchup MERIS spectra are inverted to IOP and compared to the measured ones.
The total uncertainty is the sum of three error components:

$$\sigma_t^2 = \sigma_{atm}^2 + \sigma_{noise}^2 + \sigma_{inv}^2$$

<table>
<thead>
<tr>
<th>Error %</th>
<th>model</th>
<th>noise</th>
<th>atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>40</td>
<td>13</td>
<td>47</td>
</tr>
<tr>
<td>CDOM</td>
<td>41</td>
<td>13</td>
<td>46</td>
</tr>
<tr>
<td>SPM</td>
<td>45</td>
<td>5</td>
<td>50</td>
</tr>
</tbody>
</table>

The challenge is that the reliability varies with how dirty the air is and how turbid the water is?

Turbidity is the challenge!

Salama and Shen (ECSS, 2010)
Water turbidity reduces observed radiometric variability: radiometric variability is higher for clear water than for turbid water.

Water turbidity complicates the correction and retrievals...

Errors: model parameterization setup

Inherent error of model parameterization setup

Salama and Shen, 2010, Optics Express, 18, 479–499

UNIVERSITY OF TWENTE.
Spatial mismatch

Velde, Salama et al., 2012
Hydrometeorology,

Reduced resolution → higher errors!!!
How can we derive $K_d(z)$?

Old but gold!, the Duntley (1942) two steams model:

$$\frac{dE_{ds}}{dz} = kE_{ds} ; \quad \frac{dE_{dd}}{dz} = -s' E_{ds} + \alpha E_{dd} - \beta E_u$$

$$\frac{dE_u}{dz} = sE_{ds} + \beta E_{dd} - \alpha E_u$$

Solving and accounting for singularity gives

$$E_d(z) = E_{ds}(0) \exp(kz) + E_{dd}(0) \exp(mz) + (s' + \beta r_{sd}^{\infty}) J_1(z) E_{ds}(0)$$

this does not describe a purely exponential attenuation of the flux with depth, since two extinction coefficients are involved, $k$ and $m$. 
Results

Versus Hydrolight at different depths

(a, z=0)

R\textsuperscript{2}=1
MAD=0.013084
Intercept=-0.011678
Slop=1

(b, z=5)

R\textsuperscript{2}=0.994
MAD=0.04096
Intercept=-0.030415
Slop=0.98338

(c, z=10)

R\textsuperscript{2}=0.994
MAD=0.043305
Intercept=-0.037264
Slop=0.99874

(d, z=20)

R\textsuperscript{2}=0.994
MAD=0.045494
Intercept=-0.040532
Slop=1.0011
Results

Versus in-situ measured $Ed(z= 50 \text{ cm})$ and $Ed(z=100 \text{ cm})$

<table>
<thead>
<tr>
<th></th>
<th>$K_{dd}(440)$ (m$^{-1}$)</th>
<th>$K_{dd}(490)$ (m$^{-1}$)</th>
<th>$K_{dd}(550)$ (m$^{-1}$)</th>
<th>$K_{dd}(670)$ (m$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.913</td>
<td>0.907</td>
<td>0.860</td>
<td>0.595</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.091</td>
<td>0.182</td>
<td>0.107</td>
<td>0.744</td>
</tr>
<tr>
<td>Slope</td>
<td>1.089</td>
<td>0.907</td>
<td>0.824</td>
<td>0.584</td>
</tr>
<tr>
<td>RMSE (m$^{-1}$)</td>
<td>1.086</td>
<td>0.640</td>
<td>0.547</td>
<td>0.540</td>
</tr>
<tr>
<td>MRE (%)</td>
<td>26.4</td>
<td>26.6</td>
<td>32.9</td>
<td>42.4</td>
</tr>
</tbody>
</table>
Preliminary conclusions

- Empirical models are ok but limited; we will apply GeoCalVal;

- Semi analytical model with NAP and spectral slopes is acceptable;

- We can derive Kd depth profile; and improve on the forward model.
Thank You!!